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Experimental investigation on the effect of soil solarization incorporating black, silver, and transparent polythene, and straw as mulch, on the microbial population and weed growth

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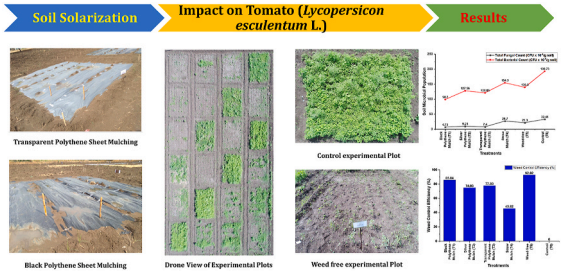
HIGHLIGHTS

- Soil solarization with black, silver, transparent polythene, and soyabean straw mulch on microbial count and weed growth.
- Black polythene mulch sheet (T1) reduced bacteria by 48.78%, whereas control (T6) had the most fungus.
- Mean total weed count ha^{-1} increased from 15 DAT (16281) to 45 DAT (24770).
- Weed dry weight was highest in the control (3.02 t/ha^{-1}).
- Weed-free (T5) had the highest weed control efficacy (92.82%), followed by black polythene (T1) with 85.84%.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil solarization is a non-chemical method for eliminating crop-threatening weeds and selectively decontaminating soil. The effect of various soil solarization with black, silver, transparent polythene sheet and straw as mulching on the microbial count and weed growth was studied experimentally. The farm investigation comprised six soil solarization treatments: mulching with black, silver, and transparent polyethylene sheets of 25 μm (μ), organic mulch (soybean Straw), weed-free, and control. All six treatments were repeated in four sets in a Randomized Block Design (RBD) plot size of 5.4 m × 4.8 m. Black, silver, and transparent polythene mulches significantly reduced fungal count compared to non-solarized soil. Straw mulch significantly increased soil fungal count. Solarized treatments had much lower bacterial populations than straw mulch, weed-free, and control treatments. Black, silver, straw mulch, and transparent polythene had 18746, 22763, 23999, and 3048 weeds ha^{-1} at 45 days after transplanting (DAT). The analysis of dry weed weight demonstrated a significantly low weed dry weight of 0.44 t/ha for black polythene (T_1) based soil solarization, representing an 86.66% reduction in dry weed biomass. Soil solarization had the lowest weed index (WI), with black polythene mulch (T_1) reducing weed competition. Among various soil solarization treatments, black polythene (T_1) showed the highest weed control efficiency of 85.84%, indicating its suitability for use in weed control. The results suggest that soil

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solarization is effective for soil disinfestation and weed control with polyethene mulch and summer heat in central India.

1. Introduction

Soil as a growing medium and nutrient source for crops is of prime importance in management. Crop roots grow in soil and extract soil water and solutes from the rhizosphere. The rhizosphere, soil surrounding the root zone of plants, is a dynamic medium where numerous physical, chemical, and biological processes are taking place, which is interdependent and interlinked. Soil also harbours an omnipresent microbial biosphere with different fungal, bacterial, and countless other populations (Gupta et al., 2017). Microbes are environmentally, economically, and socially significant. Microorganisms are primarily known as the etiological agents of disease (i.e., the causes of disease). Microorganisms are classified into three groups: mesophiles, whose temperatures range for optimal growth is between 20 °C and 45 °C, whereas the microbes that thrive in a cold environment are psychrophiles, and 15 °C–20 °C its optimal growth temperature ranges. Microorganisms surviving at higher optimum growth temperatures at 50 °C to higher are thermophiles (Rahman et al., 2021). The biology of the soil is hugely influenced by soil temperature. Feng and Simpson (2009) reported changes in the diversity of microorganisms with changes in the soil temperature range from 2 °C to 20 °C.

Topsoil is also a weed seed bank, which retains weed seeds shaded by mother weed plants during the previous seasons. These seeds germinate in flushes as the congenial conditions of soil moisture and temperature coincide and thus persists in the ecosystem, threatening crop by competing for limited soil moisture, valuable nutrients, and space in the rhizosphere (Nysanth et al., 2022). Pests, including insects, diseases, and weeds, exert stress on crops, leading to reduced growth, yield, and quality of the product. Management of pests in the harvest by chemical method disturbs the natural ecosystem by including chemicals in the raw food chain (Okeke et al., 2022). In contrast, mechanical weed control is laborious, energy, and time-consuming (Machleb et al., 2020).

Katan and Gamliel (2014) introduced soil solarization for pre-plant soil disinfestation of field crops. Soil solarization is a non-chemical approach for treating soil-borne pests by covering pre-soaked soil for 30–40 days before planting with polyethene film to harness the sun's radiant energy to elevate temperatures during the hot summer months. Several tropical nations throughout the world studied soil solarization. Egypt, Cameroon, Libya, Morocco, Sudan, Tunisia, and South Africa are tropical countries where soil solarization has been proven (Castello et al., 2017). The use of organic mulches for soil coverage is one of the natural means of avoiding weed invasion. A positive effect of mulch is discernible during the period of intensive weed germination (Sofi et al., 2014). While efficient soil disinfested with phytopathogenic fungus and weed seeds was reported by Simmons et al. (2016). Jamieson et al. reported that the plastic mulches increase soil temperature to the range of 4 °C to 5 °C at a 5 cm depth underneath black and clear mulch, which has the advantages of using for soil solarization, decreasing compaction of soil, water losses through evaporation, and menace of weeds (Jamieson et al., 2005). Still, mulches are ineffective against perennial weeds, which are persistent (Green et al., 2003; Candido et al., 2008).

Di Mola et al. (2021) described the benefits of plastic mulching for eggplant crops, with black and photo-selective polythene being preferable to transparent polythene for weed control. Smith et al. (2018) reported better weed control in eggplant, cowpea, and sweet potato by mulched than un-mulched plots.

Several Researchers have reported that solarization of the soil lowers soil-borne plant diseases (Mauromicale et al., 2010; Balakrishna et al., 2015). In addition, to decrease the incidence of disease besides its severity, increased plant growth and crop yield are observed. The previous studies reporting reduced densities of the soil-borne pathogens are confined to target organisms. Dwivedi and Dwivedi (2020) presented the effective control of wilt disease causing two pathogenic soil fusaria, i.e. *Fusarium solani* and *Fusarium oxysporum* in guava by soil solarization. The consequence of soil solarization on a broader range of microflora, counting those that are aggressive to plant pathogens, was reported.

Soil-borne pathogens and pests of tomatoes include fungi, bacteria, and weeds. Fungi cause the most important fungal diseases (Abd-Elgawad et al., 2019). These include (i) root and crown rots, incited primarily by species of *Pythium, Phytophthora*, *Fusarium,* and *Rhizoctonia* (Mansoori, 2020; Ouyang et al., 2019; Salerno et al., 2000; Wu et al., 2014). (ii) vascular wilts due to *Fusarium oxysporum, f.sp. lycopersici*, Verticillium *dahlias* (Basseto et al., 2011), and (iii) corky root rot (causal organism *Pyrenochaeta lycopersici)*. Among soil-borne bacterial diseases, only the newly detected bacterial canker (causal organism *Clavibacter michiganensis* subsp. *Michiganensis)* appears to be of potential economic importance (Ioannou, 2000). Root-knot nematodes (*Meloidogyne* spp.) Polythene films used for soil mulching protect against the infection and development of soil-borne diseases (Luvisi et al., 2015).

Several studies on soil solarization have been reported from tropical areas. There is considerable growth in mulching in tropical agricultural regions. Though, the result of soil solarization on soil microbial count and weeds growth has not been testified for Indian tropical areas, viz. Maharashtra and Central India. So, the experimental trial on the effects of soil solarization on soil microbial count and weeds growth in tomatoes (*Lycopersicon esculentum* L.) was performed. The impact of black, silver, and transparent polythene and straw as mulch on soil microbial count weeds growth in tomatoes (*Lycopersicon esculentum* L.) was evaluated.

2. Material and methods

2.1. Experimental site

The experiment was conducted in two parts pre-planting soil solarization treatment during the hot summer season of 2019 and transplanting of tomato seedlings during Kharif 2019 at the Agronomy Departmental farm, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, located in the Marathwada region of Maharashtra State at 19° 16′ N latitude, 76° 47′ E longitude with an altitude of 409 m above the mean sea level.

2.2. Land preparation

Effective soil solarization is possible when there is close contact between soil and soil covering material. Traditional ploughing, harrowing, and cleaning were used to fine-tilth the soil for the best protective film-soil connection. Pre-soaking irrigation up to 60 mm depth was given to moisten the soil before treatment allocation of soil solarization. At field capacity, soil solarization treatments were administered.

2.3. Scheme of the experiment

The farm investigation comprised six soil solarization treatments with three different polyethylene black, silver, and transparent sheets of 25 μm (μ) thickness, organic mulch (soybean Straw), weed-free, and control was repeated in four sets in a Randomized Block Design (RBD) of plot size of 5.4 m × 4.8 m. Soil solarization treatments are presented in Table 1.

Table 1
Different soil solarization treatments.

T_1	Black polythene sheet
T_2	Silver polythene sheet
T_3	Transparent polythene sheet
T_4	Straw mulch
T_5	Weed-free plot
T_6	Control

2.4. Administration of soil solarization treatment

Soil solarization treatments under investigation were allotted in which the entire treatment plot was covered by different polythene sheets of 25 μ thickness, i.e. black (T_1), silver (T_2), and transparent (T_3). Plastic sheets were laid on moist soil at least wind speed. The edges of plastic films were suppressed in the soil along the boundaries of the plot. Weights were placed on the sheeting to prevent flapping and tearing off sheets. In case of damage or holes in the polyethylene, sheets were closed immediately to avoid heat leaking. Any human or animal movement into mulched plots was restricted. For forming straw mulch in treatment (T_4), the entire plot soil surface was covered by 12.5 kg plot^{-1} (5 t ha^{-1}) soybean straw. Hydrothermal processes initiated due to the trapping of solar radiation in soil solarized plots raise soil temperature. As a buffer zone, a distance of 0.5 m was maintained between each pair of plots so that the individual treatment effect would not be affected by neighbouring plots and so that different solarization and non-solarization treatments could benefit from heat dilution.

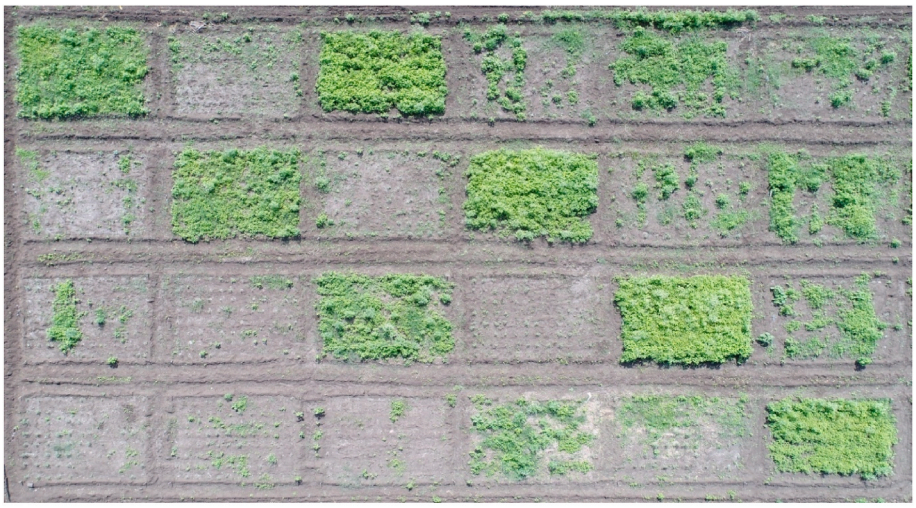
While laying, plastic sheeting immediate contact with the soil surface was maintained. It was retained on the soil surface till the commencement of the *Monsoon* (2nd fortnight of June), and tomato seedlings from the nursery were planted immediately after the removal of polythene sheets. In the case of straw mulch treatment, soybean residue was retained on particular plots. The treatment of the weed-free condition was maintained by repeated hand weddings, and in control plots, weeds were not removed during the tomato crop cultivation period. Fig. 1(a) presents the experimental field's drone-based image, and Fig. 1(b) and (c) show the polythene mulch and soybean straw mulch on the field.

3. Results and discussion

The experimental field research was conducted on the "Effect of soil solarization on the microbial count and weeds growth in tomato (*Lycopersicon esculentum* L.)" during summer and *Kharif* 2019 at of Agronomy Departmental Research Farm, VNMKV, Parbhani. The effect of various soil solarization treatments on the microbial count, weed count and weed dry weight, weed index, and weed control efficiency in tomatoes (*Lycopersicon esculentum* L.) are presented and discussed. The experimental results from the investigation, along with possible explanations and support for evaluating the cause-and-effect relationship among various treatments and investigated parameters.

3.1. Effect of soil solarization on soil microbial count

Soil solarization is the heating of soil by the sun for non-chemical weed control and partial de-infestation. Soil solarization raises soil temperature, and the temperature has a direct effect on microbial activity (Jagtap et al., 2022). The microbial population in the soil also is influenced by soil temperature.



(a)

(b)

(c)

Fig. 1. (a) Drone view of the experimental plots, (b) plastic mulched plots, (c) side view of various plastic and straw mulched experimental plots.

3.1.1. Effect of soil solarization on fungal colony count

Fig. 2 presents the total fungal count (colony/plate) as influenced by various soil solarization treatments. All the polythene mulches significantly reduced the total fungal count compared to non-solarized soil (32.46 CFU × 10^{-4}/g soil). The black mulch has recorded a reduced total fungal count of 6.73 CFU × 10^{-4}/g soil, and transparent polythene mulch also recorded a significantly lesser number of total fungi colonies, i.e., 7.4 CFU × 10^{-4}/g soil as compared to silver polythene sheet 9.23 CFU × 10^{-4}/g soil. The organic mulch (soil covered by straw mulch) showed total fungal count of 26.7 CFU × 10^{-4}/g soil. The effectiveness of black mulch was more than the transparent and reduced the total fungal counts compared with the control. Soil solarization harnesses solar radiation. It increases the duration of daily soil temperature, which may have decreased the fungal population (Bonanomi et al., 2008; Sarathchandra et al., 1995).

Various treatments significantly influenced the fungal population of soil in Fig. 2. Soil solarization with black polythene mulch sheet (T_1) resulted in a significant reduction of 79.28% in the fungal population, which is significantly higher than the transparent polythene mulch sheet (T_3), silver polythene mulch sheet (T_2), weed free plot (T_5), and straw mulching (T_4) by 77.20%, 71.56%, 65.61% and 17.74% respectively. The control treatment (T_6) was higher in fungi population colony count compared to all treatments, therefore demonstrating the efficacy of solarization in minimizing fungal infections. Teasdale et al. (2000) reported that straw mulch is an effective method for enhancing the soil's biological activity.

3.1.2. Effect of soil solarization on bacterial colony count

Various treatments significantly influenced the bacterial population of soil, as depicted in Fig. 2. Data on total bacteria count (colony/plate) of soil solarization influenced by different treatments are presented in Fig. 2. The total bacterial colony count recorded by non-solarized soil (T_6), i.e., control, was highest (192.73 CFU × 10^{-6}/g soil) followed by treatments (T_5), i.e., weed free (139.3 CFU × 10^{-6}/g soil). All the solarized treatments recorded significantly less bacterial population compared to the control. The treatment T_1, i.e., the black polythene sheet, recorded a significantly lesser bacterial colony count, 98.7 CFU × 10^{-6}/g soil. Between the colours of polythene sheets, the transparent mulching sheet (T_3) recorded a less mean total bacterial population of 120.86 CFU × 10^{-6}/g soil compared to the silver colour of polythene sheets (T_2) 127.56 CFU × 10^{-6}/g soil and straw mulch (T_4) 154.3 CFU × 10^{-6}/g soil. Soil solarization with black polythene mulch sheet (T_1) resulted in a significant reduction in (48.78%) bacterial population, significantly superior to the rest of the treatments. **Solar heating and trapped heat in mulched soil increase soil temperature.** As the daily soil temperature increased, the bacterial population decreased (Jones et al., 2021; Li et al., 2022).

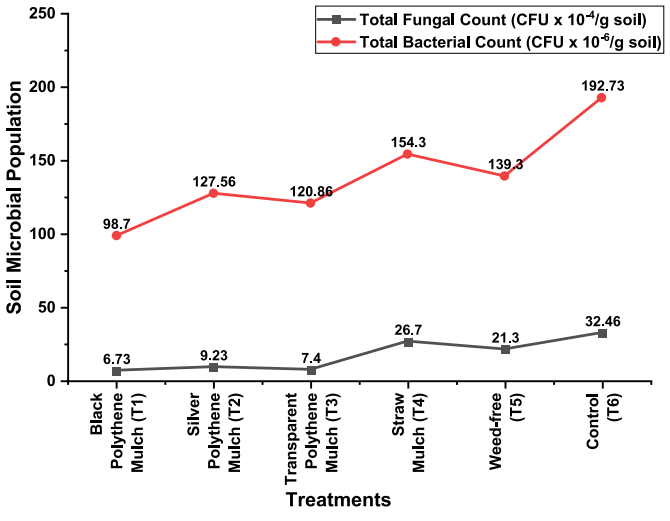


Fig. 2. Total fungal and total bacterial count (colony/plate) as influenced by different soil solarization treatments (CFU = colony forming unit).

3.2. Effect of soil solarization on weed control

3.2.1. Weed flora of experimental plots

Table 2 presents pre-dominant weed species of grasses (perennial and annual), broad-leaved (annual) and sedges (perennial) were observed in experimental fields. Perennial weeds propagate by vegetative parts threats more as they are difficult to control.

3.2.2. Weed count (ha^{-1})

Periodical data on weed count ha^{-1} up to 45 DAT from the day of removing soil solarization treatment was recorded and presented in Fig. 3. It is combined and represented every 15 days up to 45 days. Total weed count ha^{-1} was observed as 4738, 8240, 12978, and 15244 at 15 DAT for black polyethene, transparent polythene, straw mulch and silver polyethene, respectively. At 30 DAT, total weed count ha^{-1} was 8858, 20600, 20909, and 27089 for black polyethene, silver polythene, straw mulch and transparent polythene, respectively. At 45 DAT, the total weed count ha^{-1} was 18746, 22763, 23999, and 30488 for black polyethene, silver polythene, straw mulch and transparent polythene, respectively.

To administer the control treatment (T_6), all weeds were retained, and the plot was not weeded, resulting in a high total weed count of ha^{-1} at each stage. Among the polythene mulches, the significantly lowest weed count of monocot weeds was recorded by black polyethene at 15 DAT, 30 DAT, and 45 DAT. The dicot weed count in black polythene sheets at 15 DAT and 30 DAT reported significantly lower values than the rest of all treatments except at 45 DAT. In total weed count of all treatments, dicot weed count was higher than monocot. The lowest monocot and total weed count at 45 DAT were recorded by treatment T_1, i.e., soil solarization with black polythene sheet, and were significantly superior over the rest. The results highlight the effectiveness of the black polythene sheets in soil solarization and efficiency in weed control. The data of weed count from the present study also revealed that the perennial weed count of (Nutgrass-*Cyprus rotundus* and Harali or Bermuda grass- *Cynodon dyctylon*) recorded by the transparent polythene sheets (T_3) was low at 15 DAT. At the same time, at 30 DAT and at 45 DAT, it increased. Among the polythene sheets, black and silver polythene sheets blocked the entry of photosynthetically active radiation or/and incident short wave radiation or sunlight into the soil (Ding et al., 2021). They have stopped short-wave solar radiation by black mulch, and trapping of heat increased soil temperature, which subjected the vegetative propagation parts of the perennial weeds to starvation and deterioration. This is reflected in the count of perennial monocot weeds (grasses and sedges) (Acharya et al., 2018). In contrast, the transparent polythene sheet trapped heat, which weakened the vegetative propagation parts of the perennial weeds, but as it allowed to pass a small amount of sunlight through it, so the starving and deterioration was low, which recovered with time and favourable conditions of sunlight, soil moisture, and soil temperatures (He et al., 2021).

Table 2
Weed flora of experimental plots.

S. No.	Name of the weed	Weed type
1	Nutgrass- *Cyprus rotundus*	Monocot
2	Harali- *Cynodon dyctylon*	Monocot
3	Hajardani- *Phyllanthus niruri*	Monocot
4	Cana-*Commelina bengalensis*	Monocot
5	Orchard Grass- *Dactylis glomerata*	Monocot
6	Alternanthera	Monocot
7	Digerra- *Digera arvensis*	Dicots
8	Datura- *Datura metel*	Dicots

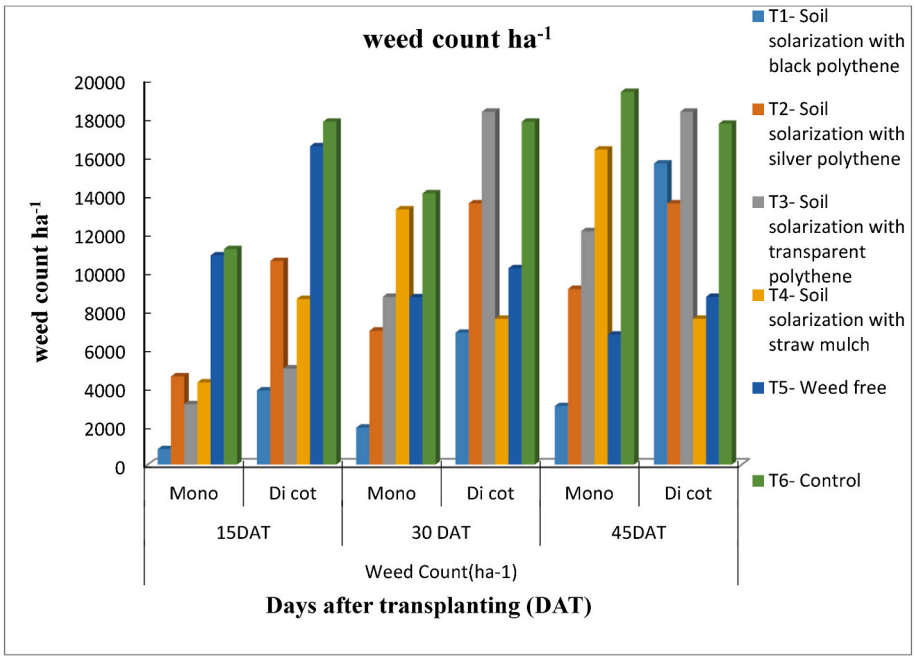


Fig. 3. Weed count ha^{-1} as influenced by different soil solarization treatments after removal of polythene.

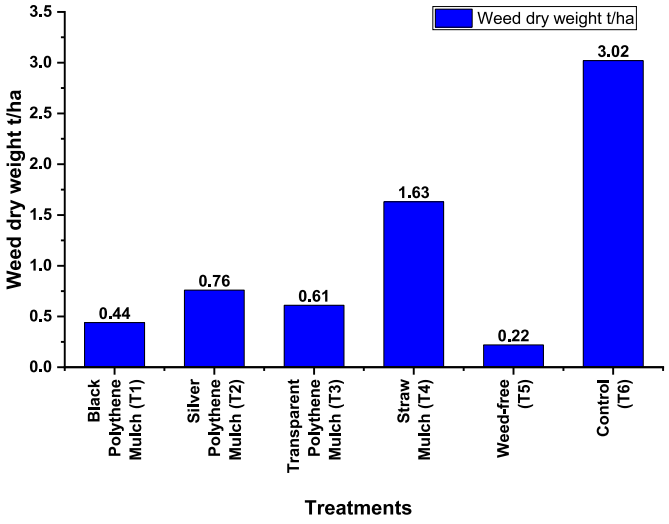


Fig. 4. Mean dry weed weight (t/ha) influenced by different soil solarization treatments.

3.2.3. Weed dry weight (t/ha) at harvest

Fig. 4 provides statistics on mean weed dry weight (t/ha) at harvest of tomato crops as influenced by various soil solarization treatments.

The dry weed weight analysis revealed that a significantly low weed dry weight of 0.22 t/ha at harvest was observed for tomato crops in weed-free (T_5) treatment followed by 0.44 t/ha black polythene (T_1) based soil solarization and the reduction in dry weed biomass over control was 93.33% and 86.66% respectively. Grassbaugh et al. (2004) reported that black polythene resulted in an 80% reduction in weed biomass which is close to the observed result with the black polythene-based soil solarization. Ham et al. (1993) reported that black polyethene is the most popular because it prevents weed growth and warms the soil in the spring, in addition to its low cost. Further weed dry weight of 0.61 t/ha, 0.76 t/ha and 1.63 t/ha for transparent, silver and straw mulch, respectively. The highest weed dry weight was recorded in the control (3.02 t/ha). The weed emergence and the weed dry weight were significantly reduced in the polythene covered (Mulched) plots in comparison with the non-solarized plots due to the solarization of the soil which reduced the germination of the weed seed. This study shows that weed-free treatment and soil solarization with black polythene sheets both reduce crop-weed competition for tomatoes.

Table 3
Weed Index (WI) as influenced by different soil solarization treatments.

Sr. No	Treatment	WI.
1	Black polythene mulch (T_1)	4.59
2	Silver polyethene mulch (T_2)	10.80
3	Transparent polyethylene mulch (T_3)	14.77
4	Straw mulch (T_4)	37.97
5	Weed-free (T_5)	0.00
6	Control (T_6)	66.76

3.2.4. Weed index

The weed index is the percentage decrease in seed yield resulting from the presence of weeds in a particular treatment relative to the seed yield achieved in a weed-free plot (Hemanth Kumar and Jagannath, 2021). Mathematically it is calculated using the following equation

$$Weed\ index\ (\%) = \frac{yield\ from\ weed\ free\ plot - yield\ from\ treated\ plot}{yield\ from\ weed\ free\ plot} \times 100$$

Table 3 represents the weed index, indicating weeds' competitiveness for treatment. The weed index's lower value reflects less competition for the crop. Among the soil solarization treatments, soil solarization with black polythene mulch (T_1) recorded the lowest weed index, reflecting its effectiveness in controlling weed competition. The second lowest weed index was silver polythene mulch (T_2), followed by transparent polythene mulch (T_3) and straw mulch (T_4).

3.2.5. Weed control efficiency (WCE.)

Weed control efficiency is a measure of the percentage reduction in weed population or dry weight of weeds under a treated plot in comparison with the untreated plot (control). Weed control efficiency is used to compare the different control treatments. The higher the weed control efficiency better is the weed control treatment (Nath et al., 2021). Mathematically it is calculated using the following equation

$$Weed\ control\ efficiency\ (\%) = \frac{Dry\ weed\ weight\ in\ weed\ free\ plot - Dry\ weed\ weight\ in\ treated\ plot}{Dry\ weed\ weight\ inweed\ free\ plot} \times 100$$

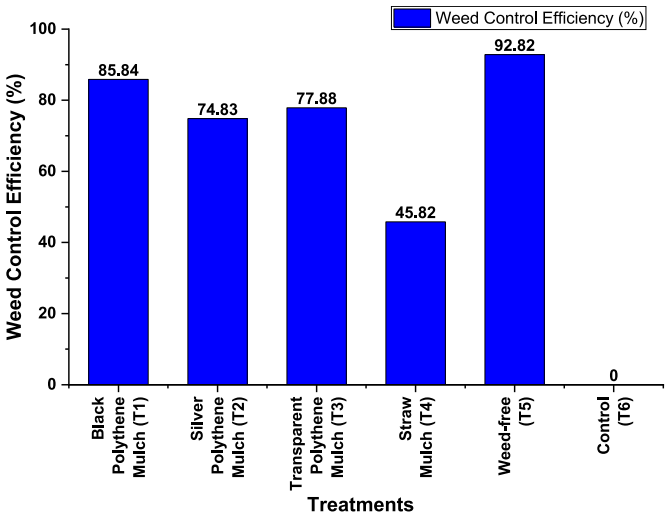


Fig. 5. Mean weed control efficiency as influenced by different soil solarization treatments after removal of polythene.

The weed control efficiency (WCE) of tomatoes was influenced by different soil solarization treatments shown in Fig. 5. Weed control efficiency (WCE) of various treatments showed that weed-free (T_5) had maximum weed control efficiency of 92.82%, followed by black polythene (T_1), with 85.84%, which is comparable with the (Safdar et al., 2021). Further, silver mulch (T_2) and transparent mulch (T_3) had a weed control efficiency of 74.83 and 77.88%, respectively; straw mulch (T_4) had a weed control efficiency of 45.82%, which is the lowest among soil solarization treatments.

4. Conclusions

The present study compared the effects of various solarization materials used for soil solarization on soil microbial count, weed count, and weed control efficacy. From the experimental trials, it was observed that soil solarization reduces the total number of soil-borne microflora (Fungi) by 79.28%, 77.20%, 71.56%, and 17.74% for black, transparent, silver and straw mulch, respectively. The total bacterial count was reduced by 48.79%, 37.29%, 33.81%, and 19.94% for black, transparent, silver and straw mulch, respectively. Black polythene mulch provided the best performance in reducing soil-borne micro-flora, such as fungus and bacteria. Solarization reduces monocot weeds more than dicots. The total weed count ha^{-1} for black polythene, silver polythene, straw mulch, and transparent polythene at 45 DAT was 18746, 22763, 23999, and 3048, respectively. The dry weed weight analysis showed a significantly low weed dry weight of 0.44 t/ha for black polythene (T_1) based soil solarization, reducing dry weed biomass by 86.66%. Black, silver, transparent, and straw mulch had weed indexes of 4.59, 10.80, 14.77, and 37.97, respectively. Weed control efficiency for soil solarization based on black polyethylene (T_1) has been 85.84%. Black polythene mulch effectively reduced weed count, weed growth, dry weight, and weed index more than silver, transparent, or straw mulch. The comprehensive study showed that soil solarization is effective for soil disinfestation and weed control with all colours of polyethene mulch and the use of summer heat for soil solarization in the central region of India.

Authorship statement

Yogesh A Shinde: Conceptualization, Literature review, field experimentation, writing original draft. **Megha P Jagtap:** Conceptualization, Data curation. **Minakshi G Patil:** Conceptualization, Data curation, Analysis of results, **Narendra Khatri:** Literature review, Data curation, Writing- Original draft preparation, and Correspondence.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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